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M. J. Hanshaw

J. L. Gaddy
Missouri University of Science and Technology

ENERGY CONVERSION AND RESOURCE MANAGEMENT

M. J. Hanshaw and J. L. Gaddy
Department of Chemical Engineering
University of Missouri-Rolla
Rolla, Missouri 65401

The United States has 5 percent of the world's population, yet consumes 35 percent of the total energy. This statistic reflects the availability of unlimited and cheap energy that has been enjoyed in this country. Unfortunately, this energy has been provided without much regard for the future, so that plentiful and cheap energy may not be possible much longer. A carefully formulated energy policy will be required to manage our remaining natural resources wisely and extend their longevity until other sources of energy can be developed.

There are five basic forms of energy: chemical, thermal, electrical, mechanical and radiant. Energy is consumed primarily in the thermal, electrical and mechanical forms. However, the source of almost all of our energy is chemical (petroleum or coal); so that conversions of chemical energy are necessary steps in our energy economy.

1. ENERGY CONVERSIONS

Considering the five basic energy forms, there are twenty-five possible energy conversion steps. Ten of the most common conversions are shown in Table I. Single energy conversions are usually incomplete with losses resulting from formation of undesired forms of energy. The degree of completion of an energy conversion can be expressed by an efficiency, e, defined as the net energy available in the desired form, divided by the total energy available before conversion. Table I also lists typical conversion efficiencies for several processes. For example, 88 percent of the chemical energy available in coal can be converted to thermal energy as steam in a boiler; the remainder being lost in the flue gases.

Direct conversion of the energy resource into the desired form is not frequently possible; and several conversion steps may be required. Table II lists the conversion steps required to derive electricity, heat and transportation from chemical energy sources. The efficiency of combinatorial energy conversions is given by Equation (1):

$$E = \prod_{i=1}^{N} e_i \qquad (1)$$

where E = net conversion efficiency
e = efficiency for step i

For example, electricity is generated from chemical energy by making these conversions: chem→therm(boiler), therm→mech (turbine) and mech→elec (generator). Using Equation (1) and the data from Table I, the efficiency, E, of this conversion is: (.88)(.45)(.99) = .39.

Electricity, space heating and transportation represent the largest individual uses of energy in this country. Table II gives the efficiencies of several processes for producing energy for these requirements. It is distressing to realize that the overall efficiency of our utilization of chemical energy for the above uses is only about 35 percent, not including losses in the transportation of energy (compared to an overall efficiency of 50 percent (2)). This poor efficiency suggests an examination of our conversion practices in developing an energy policy for the future.

It is interesting to observe from Table II that the fuel cell offers a means of about doubling the efficiency of electricity generation and motive power. Also, direct combustion is more efficient in providing space heat than the electric furnace. The gasoline pwoered automobile is slightly less efficient than a battery driven car, powered by electricity generated from the same gasoline.

2. RESERVES OF CHEMICAL ENERGY

Decisions as to the prudent use of our chemical energy resources cannot be made without reference to the reserve of these resources. It would not be wise for example, to use gas for space heating when out natural gas reserves are rapidly dwindling. Table III presents the proven recoverable reserves of our chemical energy resources. The life of these reserves can be estimated by Equation (2):

$$A = \frac{R}{C} \tag{2}$$

where A = availability of reserves, yrs.
R = current quantity of proven reserve
C = annual rate of consumption of reserve

This availability is different from the usual representation of the life of resources which is computed from the current production, rather than the consumption. While it is recognized that both R and C change with time, probably increasing, it is assumed that these changes are offsetting so that the measured availability is realistic. Table III shows that our current reserves of petroleum would last only 5-11 years if all the demand were supplied by domestic production, while coal would last 275 years.

3. INTRINSIC ENERGY CONVERSIONS

The data of Table III show the heavy dependence that must be placed on coal in the future. There is incentive to convert coal into gas and oil more desirable energy forms. These are intrinsic conversions of one form of chemical energy to another form of chemical energy. These conversions are for convenience, i.e., it is more convenient to burn gas in home furnaces than to stoke coal.

Intrinsic energy conversions consume energy, resulting in a reduction of the efficiency of the converison. Table IV lists several intrinsic chem chem energy transformations, along with their efficiencies. These efficiencies should be influential in establishing a wise allocation of our resources.

4. A RATIONAL ENERGY POLICY

The availability of an energy reserve, calculated by Equation (2), is not an effective measure of the expected life of that resource, since neither the demand nor efficiency of utilization is included. A better measure is to consider the annual quantity of a resource allocated to a certain need, calculated as:

$$RA = \frac{D}{(R)(E)} \times 100 \qquad (3)$$

where RA = resource allocation, %/yr.
D = current annual demand for a particular form of energy (output)
E = efficiency of converting resource into the energy form used

For example, the demand in 1975 for space heating is 6.1×10^{15} BTU (output/yr. (input reported as 12.2×10^{15} BTU (1,5,11)). If this energy requirement is provided by gas, the resource allocation, RA is:

$$RA = \frac{6.1 \times 10^{15} \times 100}{(237 \times 10^{15})(.5)} = 5.2\%/\text{yr.}$$

Of course, it is unreasonable to assume that all of a certain demand will be met from a single energy source. The equation can accommodate the use of a fraction of demand to be allocated to a particular resource. Allocations to supply the space heating, electricity generation and transportation needs are given in Table V.

4.1 SPACE HEATING

From Table II, the most efficient means of providing space heating is by direct combustion of oil, gas or coal. To use either gas or oil for this purpose would deplete these reserves at the rate of about 5-6 percent per year. Therefore, coal should be the fuel allocated for this need. However, the use of coal for heating individual homes is certainly undesirable.

Space heating would be provided by electricity generated from coal with an overall efficiency of 39 percent and a coal allocation for heating of .4 percent per year. Coal can be converted to gas to provide space heating with an efficiency of 32 percent and an allocation of .5 percent per year. Obviously, there is little incentive to develop coal gasification for providing the requirement of space heating.* Our energy policy should clearly be directed towards provision of heating with electricity generated from coal or nuclear energy. This policy, of course, necessitates the solution of the SO_2 stack gas problem.

4.2 TRANSPORTATION

The output energy demand for transportation in 1975 is 4.4×10^{15} BTU (input reported at 17.6×10^{15} BTU (5,11)). Continued use of oil for transportation will deplete our reserves by about 9 percent per year. Conversion of coal to oil would yield an overall transportaiton efficiency of only 20 percent. However, generation of electricity with coal and the use of a battery powered auto yields an efficiency of 26 percent with a coal allocation of .4 percent per year. Clearly, an energy policy should favor the electric car and development of suitable batteries should be pursued virorously. Electric cars also are environmentally desirable, providing the environmental problems at the generating stations and coal mines can be solved.

*This comparison of heating with SNG and electricity has neglected the transportation aspects; however, the results would be little altered since the efficiency of transporting gas and electricity are about the same.

4.3 ELECTRICITY

The demand for electricity in 1975 will be about 6.1×10^{15} BTU (1). Reviewing the allocations of fuels for generating electricity given in Table V, it is seen that 7 to 8 percent of our petroleum would be consumed annually if used to generate electricity, while only .4 percent of the coal would be used. Coal must be allocated as the hydrocarbon fuel for electricity, and gas and oil should be phased out for this usage.

The conclusion of the above analysis is that, for maximum efficiency and resource conservation, an electrical energy economy should be pursued. Electricity can be generated from coal, nuclear or renewable energy sources. An electric energy economy is not possible without the development of new or improved technology for storage batteries, environmental protection and energy transmission.

5. COAL RESERVES

An economy, totally dependent upon coal as a source of energy, is not an altogether wise policy. Adding the allocations of coal for heating, trnasportation and electricity in Table V, it is found that 1.2 percent of our coal will be consumed annually. This allows only an 83 year life of our coal reserves. However, this life should be adequate for the full development of renewable energy sources or the breeder reactor.

Consider the achievement of energy sufficiency utilizing gas and oil from coal, by 1985, about the earliest date this technology will be available. The- shortage of natural gas will amount to 8×10^{15} BTU annually (12). Should these shortages be made up by gas and oil produced from coal, the availability of coal reduces to about 40 years. So coal is certainly not unlimited and this resource should be managed wisely to insure its longevity.

6. PETROCHEMICAL NEEDS

Our society is dependent upon the petrochemicals derived from oil and gas. Plastics, synthetic fertilizer, pharmaceuticals and many hundreds of other products come from oil and gas. While we have alternative sources of energy, there are few alternative sources of carbon for petrochemicals. Oil and gas can no longer be used as a source of energy and particularly as a source of heat.

The demand for chemical feedstocks is currently about 10 percent of our total energy usage (5,13). If petroleum were reserved solely for petrochemical needs, (and aircraft transport) the availability of oil and gas could be lengthened to only 46 years, not a particularly bright future. Each year of continued use of petroleum for energy, shortens the time until alternative sources of chemical feedstocks must be developed. Oil from shale and tar sands (although more expensive) will undoubtedly lengthen this horizon, but continued hesitation to implement a policy of conservation will hasten the day of total depletion.

7. CONCLUSIONS

The most efficient use of our remaining chemical energy resources can be achieved by development of an electric energy economy. This transition cannot be made immediately and without technological advancement in electric cars and environmental protection at the generating stations and coal mining facilities. However, this technology is perhaps more rapidly achieved than coal gasification, nuclear fusion or solar energy storage.

Coal gasification and liquefaction are inefficient and offer no advantage over electricity generation with coal. In fact, the efficiency of coal conversion processes must be above 80 percent before becoming competitive with electricity. Petroleum should not be depended upon as a source of energy and should be reserved for petrochemicals.

For a fifty year horizon, an energy policy emerges as follows:

1) Encourage generation of electricity with coal, even at the expense of increased SO_2 emissions. Accelerate development of stack gas scrubbing and coal mining procedures. Develop uses for waste heat at generating plants.

2) Offer incentives for electrical space heating. Phase out generation of electricity and heating with petroleum.

3) Accelerate the development of advanced storage batteries and fuel cells.

4) Develop efficient urban mass transit systems based on electric power.

5) Continue development of renewable sources of energy and implement their use as economics permit.

Quite obviously, the transition from a petroleum energy economy to a coal-electric economy could not and should not be immediate nor complete. Time is required to replace refineries with power plants, internal combustion engines with batteries, gas furnaces with electric, etc. Some uses of petroleum for energy will be necessary for many years (aviation). However, unless the transition is begun soon, heavier dependence upon imported energy and petrochemicals will result; and energy sufficiency will be impossible in the near future.

8. LITERATURE

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TABLE I. DIRECT ENERGY CONVERSION EFFICIENCIES[1]

ENERGY CONVERSION	PROCESS	CONVERSION EFFICIENCY (%)
CHEM→THERM	BOILER	88
	HOME FURNACE	50*
THERM→MECH	STEAM TURBINE	45
MECH→ELEC	GENERATOR	99
ELEC→MECH	MOTOR-SMALL	62
	LARGE	92
ELEC→RADIANT	INCADESCENT LAMP	5
	FLOURESCENT LAMP	20
	GAS LASER	40
ELEC⇄CHEM	STORAGE BATTERY	72
CHEM→ELEC	DRY CELL BATTERY	92
	FUEL CELL	60
RAD→ELEC	SOLAR CELL	10
THER→ELEC	THERMOCOUPLE	8
THER→MECH	GAS TURBINE	35
	AUTO ENGINE	25
ELEC→THER	RESISTANCE HEATER	100

*Home furnaces rated as high as 75 percent, but applied efficiency usually 35-50 percent.[1]

TABLE II. COMBINED ENERGY CONVERSIONS

REQUIREMENT	EXAMPLE	ENERGY CONVERSION PROCESSES	COMBINED EFFICIENCY (%)
ELECTRICITY	POWER PLANT	CHEM→THERM→MECH→ELEC	39
	GAS TURBINE GENERATOR	CHEM(GAS)→THERM→MECH→ELEC	32
	FUEL CELL	CHEM→ELEC	60
SPACE HEATING	ELECTRIC FURNACE	CHEM→THERM→MECH→ELEC→THERM	39
	GAS, OIL OR COAL FURNACE	CHEM→THERM	50
TRANSPORTATION	INTERNAL COMB. ENG.	CHEM(OIL)→THERM→MECH	25
	BATTERY POWERED	CHEM→THERM→MECH→ELEC→CHEM→ELEC→MECH	26
	FUEL CELL	CHEM→ELEC→MECH	55

TABLE III. AVAILABILITY OF U.S. CHEMICAL ENERGY RESERVES

CHEMICAL ENERGY FORM	PROVEN RECOVERABLE RESERVES, R, 10^{15}BTU	CONSUMPTION, C 10^{15} BTU/YR***	AVAILABILITY, A YRS
GAS	237*	23	11
OIL	204*	38	5
COAL	4400**	16	275

*Exxon Data (3)

**Hottel (4), conservative estimate

***Exxon Data (5)

TABLE IV. EFFICIENCIES OF TYPICAL CHEMICAL-CHEMICAL CONVERSIONS

PROCESS	EFFICIENCY	REFERENCE
COAL→GAS	64 (average)	(6,7)
COAL→OIL	80	(9)
OIL→GAS	90	(8)
GAS→LNG	80	(10)

TABLE V. ALLOCATION OF U.S. CHEMICAL ENERGY RESERVES

		ALLOCATION, RA, %/YR		
CHEMICAL ENERGY FORM	ENERGY PROCESS	SPACE HEATING	TRANSPORTATION	ELECTRICITY
GAS		5.2	-	6.6
OIL		6.0	8.7	7.7
COAL	COAL→HEAT	.3	-	.4
	COAL→GAS→HEAT	.5	-	-
	COAL→OIL→MECH	-	.5	-
	COAL→ELEC→MECH	-	.4	-
	COAL→ELEC→HEAT	.4	-	-